REPORT DOCUMENTATION PAGE

AFRL-SR-BL-TR-00-

0812

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
		01 March 1999 - 31 August 1999

4. TITLE AND SUBTITLE
High Frequency Measurements and Validation of Electromagnetic Models in Scattering Interconnects, and Optoelectronics

5. FUNDING NUMBERS
F49620-99-1-0160

6. AUTHOR(S)
Prof. J.E. Schutt-Aine

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Illinois at Urbana Champaign
Electrical and Computer Engineering
155 Everitt Lab MC 702
1406 West Green Street
Urbana, IL 61801-2991

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFOSR
801 N. Randolph Street, Room 732
Arlington, VA 22203-1977

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
F49620-99-1-0160

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT
Approved for Public Release.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
The performance of radio frequency (RF) integrated circuits will strongly influence the versatility and portability of future wireless communication systems. With the ever increasing demands for higher band-width and capacity as well as reductions in size weight and cost, the need for more robust and efficient RF circuits is expected to increase. Currently, millimeter-wave monolithic ICs (MMICs) chip sets are under development in the 24-94 GHz range and will represent the platform for the RF components of most wireless systems. With the recent advent of micro-electro-mechanical (MEM) systems, new potentials are being discovered for applications in the RF/millimeter wave ranges. Each of the MEM classes has pro-duced compelling examples of working devices such as the tunable micromachined transmission line in the RF-extrinsic class, the shunt electrostatic microswitch capacitors in the RF-intrinsic class, and the ca-pacitively coupled micromechanical resonator in the RF-reactive class.

20001227 079

14. SUBJECT TERMS	15. NUMBER OF PAGES
	6
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT

1A
S 3-1-99
E 8-31-99

HIGH-FREQUENCY MEASUREMENTS AND VALIDATION OF ELECTROMAGNETIC MODELS IN SCATTERING, INTERCONNECTS, AND OPTOELECTRONICS

Final Report Submitted

For Instrumentation Grant

F49620-99-1-0160

by

J. E. Schutt-Ainé, W. C. Chew, and S. L. Chuang

Electromagnetics Laboratory

Department of Electrical and Computer Engineering

University of Illinois, Urbana, IL

December 1999

1. Background

The performance of radio frequency (RF) integrated circuits will strongly influence the versatility and portability of future wireless communication systems. With the ever increasing demands for higher bandwidth and capacity as well as reductions in size weight and cost, the need for more robust and efficient RF circuits is expected to increase. Currently, millimeter-wave monolithic ICs (MMICs) chip sets are under development in the 24-94 GHz range and will represent the platform for the RF components of most wireless systems. With the recent advent of micro-electro-mechanical (MEM) systems, new potentials are being discovered for applications in the RF/millimeter wave ranges. Each of the MEM classes has produced compelling examples of working devices such as the tunable micromachined transmission line in the RF-extrinsic class, the shunt electrostatic microswitch capacitors in the RF-intrinsic class, and the capacitively coupled micromechanical resonator in the RF-reactive class.

In spite of these recent advances, several barriers still remain in the RF-wireless arena before the next generation low-cost portable systems can be implemented. These barriers require more in-depth investigations in several areas of design, modeling, simulation, processing and fabrication. These barrier issues can be categorized as related to size, weight robustness, reliability and signal integrity.

Passive components such as inductors and transmission lines occupy a significantly large area in most MMIC transceivers and generally suffer from low quality (Q) factor. This represents a major obstacle in monolithic implementation of high Q filters and inductors for high-performance wireless transceivers. However, recent research efforts have demonstrated that the use of active devices in place of inductors and filters can not only provide high Q and low-loss filtering but also reduce the size of the components significantly. Through development of better active device models, active inductors, MEM filter building blocks and standardization of such active alternatives, a major step towards low-cost and fully monolithic RF and microwave transceivers can be accomplished.

Recently, an air–gap stacked spiral inductors using air–bridge technology has been introduced [1]. By stacking metal lines, inductor area can be reduced by 25%–45% and the resonance frequencies can be increased by 10%–15% compared with conventional spiral inductors. However, the increase in resonance frequencies is not enough for MMIC applications in Ku-band or higher. Micromachined spiral inductors have demonstrated improved resonance frequency by a factor of more than two, compared with devices made with conventional processing. This broadens the applicable frequency range of lumped component circuits, leading to reduced chip size at high frequencies.

Wireless communication systems are expanding rapidly leading to the proliferation of RF applications in the UHF band (0.9-3 GHz). However stringent requirements are placed to make it essential for these

applications to conform to strict technical standards and attain a high level of integration. These demands including low cost, low voltage, low power dissipation, low noise and low distortion cannot be achieved without fabricating high quality passive devices in the same substrate using the same technology [1], [2]. Therefore, recent advances in Bipolar, CMOS and BiCMOS processes have stimulated new approaches to circuit integration and architecture. This has included high conductivity multi-metal layers, low loss substrates and thick oxide to isolate components from lossy substrates. In parallel, with the insight gained from these investigations, simplified physical models and various numerical techniques have been developed to assess the performance of passive devices such as transmission lines and spiral inductors. Unfortunately, these approaches are not easily implemented in CAD tools and sometimes suffer from incompleteness. In fact, in many instances, circuits are successfully simulated but actual prototypes often fail to match the simulated results because of parasitic effects.

In real-world design geometries of spiral inductors, circuit elements are optimized by choosing accurately the dimensions, layout and technology among other characteristics in order to improve the behavior of these structures. In fact, many authors have reported high performance inductors using advances in the processing technology, powerful CAD tools and high conductivity materials [2]. Modern communication systems place stringent requirements on RF/IF filters and voltage-controlled oscillators (VCO). Although much work has been done in the integration of a radio transceiver onto a single silicon chip, many components such as band select, channel select and tuning elements of the VCO must still remain external to the chip. It is difficult to integrate these elements onto a single chip, primarily because inductors and p-n junction varactors with high quality factors are not available in standard silicon process.

2. Measurement Setup

The accurate characterization of the components and systems mentioned above is essential in the implementation of working models. This project foused on the implementation of a measurement station for the measurement of these components in the millimeter range. The system consisted of an HP 8510C network analyzer and a Cascade probe station (Fig. 1).

In the frame of this work, inductors designed with commercial CAD tools, are measured between 500MHz and 10 GHz. A full electrical characterization is achieved using the HP8510C vector Network Analyzer (VNA) and a microwave probing station. Appropriate calibration SOLT (Short, Open, Load, Thru) with high precision standard elements has been carried out in order to ensure accurate experimental results. Low order, frequency independent lumped circuit is used to fit the 2-port measurements over the desired band of frequencies.

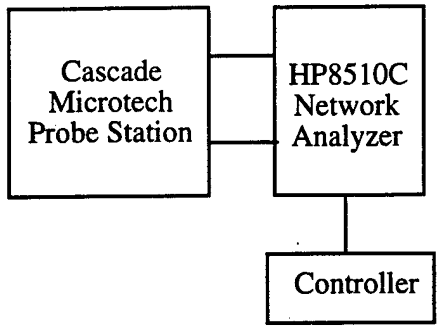

Figure 1. Measurement setup

3. Measurement of ETL and Spiral Inductors

The system was used for the characterization of embedded transmission lines (ETL) and spiral inductors using scattering parameter measurements. A simple approximation allows for the extraction of the devices characteristics, taking into account capacitive and inductive coupling as well as losses. Thus calculations can be easily and quickly performed using these models [1]-[3]. Meandered transmission lines and spiral inductors were characterized using a vector network analyzer, at frequencies from 1 to 10 GHz. These structures are shown in figure 2. Compact models addressing the behavior of these passive components are presented and a versatile technique for parameter extraction of equivalent models was proposed. Special emphasis has been placed upon the determination of coupling and conductor losses, demonstrating how these factors are of prime importance while designing RF printed or integrated circuits .

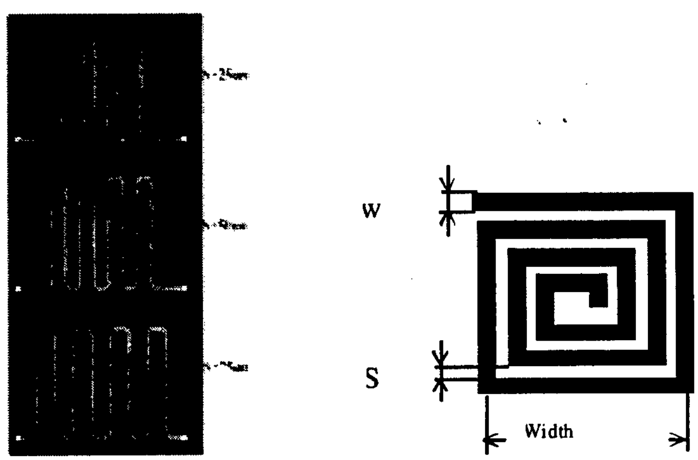

Fig.2 Meandered transmission line structure and spiral inductor

A step by step approach was adopted to study different samples of meandered transmission lines in order to visualize coupling effects when the spacing between the lines is small and to show the influence of loss on the propagation parameters [4]. Next, for spiral inductors where strong coupling is needed, atten-

tion was devoted to the electrical performance in terms of the quality factor which is strongly deteriorated by various types of losses. Measurements combined with formulation provide a basic understanding and explanation of the different aspects of these passive devices [5].

4. Measurement of MEMS Capacitors

Micromechanical systems are devices involving electrical and mechanical components and fabricated with IC batch-processing techniques. These techniques include bulk or surface micromachining, fusion bonding , electroforming, and molding and tend to make one or more movable layers over a selected part of the substrate allowing hence the mechanical motion or actuation . A photograph of a MEMS tunable capacitor is shown in Figure 3.

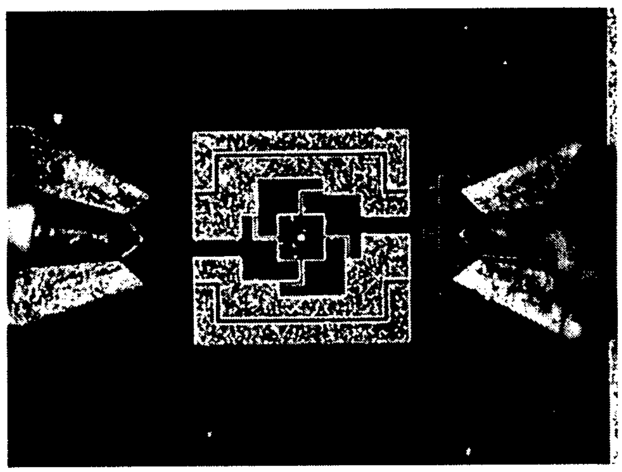

Fig.3 Measurement of MEMS tunable capacitor.

The performance of MEMS devices depends on the interaction between electrical, mechanical and fluidic forces and necessitates adequate computational tools for quick design and optimization. These tools not yet apprehended, have been used however to produce many types of MEMS products and prototype devices including transmission lines, switches various sensors micromotors, filters and oscillators in the tens of megahertz. Our work concentrated on capacitors which were the essential devices for oscillators specially in low-noise and tuning accomplishments. The bottom plate of this capacitor is fixed while the top one is mechanically suspended by four beams modeled by an equivalent spring (Fig.3). When a DC bias is applied across the capacitor plates the electrostatic force causes the suspended plate to move toward the bottom plate until an equilibrium with spring force is reached. The new separation and the area of the capacitor plates determine hence the capacitance.

5. Conclusion

Network analyzer measurements of meandered embedded transmission lines and spiral inductors were achieved. Simple equivalent models were proposed and parameters of the electrical elements were extracted employing different techniques. Measured inductances were seen to have effective values lower than the predicted results. This reduction of nominal self inductances is attributed to the coupling between the coil and the ground plane. Investigations are being carried out in this way in order to improve geometry and processing technology of micro-inductors. Losses, increasing with frequency are due mainly to skin effect and can also be reduced choosing accurately the dimensions and the arrangement of inductors layout. Measurements of MEMS tunable capacitors were also performed.

6. References

[1] Burghartz , J.N., "Spiral inductors on silicon- status and trends," International Journal of RF & Microwave Computer-Aided Engineering, vol.8, No.6, pp422-432, Nov.1998.

[2] Burghartz & al., "RF circuit Design aspects of spiral inductors on silicon, " IEEE Journal of solid-state circuits, vol.33, No.12, pp2028-2034, Dec1998

[3] L.N. Dworsky, "Modern transmission line theory and applications," John Wiley & Sons.

[4] H.A. Wheler, "Transmission line properties of parallel strips separated by a dielectric sheet," IEEE Trans. Microwave theory Tech.,vol.MTT-13,pp172-185, march 1965.

[5] P. Silvester, "TEM wave properties of microstrip transmission lines," Proc.IEEE,vol.115,pp43-48, January 1968.

[6] J.E. Shutt-Aine, R. Mittra, " Scattering parameter transient analysis of transmission lines loaded with non linear terminations," IEEE trans.Microwave Theory Tech., vol.MTT-36,pp529-536,March 1988.

[7] G. Gonzalez, "Microwave transistor amplifiers," M.A: Addison-Wesley, 1996.

[8] H.M. Greenhouse,"Design of planar rectangular microelectronic inductors," IEEE Trans. Parts, Hybrids packaging, vol.PHP-10, June 1974.

[9] H.B. Bakoglu, "Circuits, interconnections, and Packaging for VLSI," Reading MA: Addison-Wesley, 1990.

[10] M. Lopez, J.L. Prince, A.C. Cangellaris, "Influence of a floating plane on effective ground Plane Inductance in Multilayer and coplanar packages," IEEE Transactions on advanced packaging, vol.22, No.2, May 1999.

[11] J.Y. Pank, M.G. Allen, "Packaging compatible high Q micro-inductors and micro-filters for wireless applications," IEEE Transactions on advanced packaging, vol.22, No.2, May 1999.